Analysis of Near-Surface Oceanic Measurements Obtained During the Low-Wind Component of the Coupled Boundary Layers and Air-Sea Transfer (CBLAST) Experiment

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LONG-TERM GOALS

- To quantify and understand the processes that control the vertical transport of momentum and heat beneath the ocean surface.
- To evaluate and improve subgridscale parameterizations of the vertical transport processes.
- To incorporate the improved parameterizations into routinely applied numerical simulations of oceanographic processes.

OBJECTIVES

- To close momentum and heat budgets spanning the air-sea interface using direct-covariance measurements of the turbulent fluxes on both sides of the interface.
- To quantify the characteristics of Langmuir circulations and understand their relationship to wind and wave forcing.
- To quantify and understand the relative importance of shear-generated turbulence, buoyancy, Langmuir circulations, and wave breaking in accomplishing vertical transport of momentum and heat beneath the air-sea interface.
- To quantify the dominant balances in the turbulent kinetic energy and temperature variance equations.
- To evaluate the Mellor-Yamada, k-ε, KPP, and k-ω turbulence closure models.

APPROACH

The approach is to use atmospheric and oceanic measurements obtained during the low-wind component of the Coupled Boundary Layers and Air-Sea Transfer (CBLAST) program. Trowbridge and Plueddemann are focusing on turbulence statistics and Langmuir circulations, respectively, and are collaborating with Jim Edson (University of Connecticut), who is responsible for the analysis of

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atmospheric turbulence measurements obtained during CBLAST; Ming Li (University of Maryland), who is carrying out large-eddy simulations of the oceanic flows observed during CBLAST; and Greg Gerbi, a doctoral student in physical oceanography in the educational program offered by the Massachusetts Institute of Technology (MIT) and the Woods Hole Oceanographic Institution (WHOI), who is funded by this project and is working under the supervision of Trowbridge.

WORK COMPLETED

The CBLAST-low measurement program was conducted at the Martha's Vineyard Coastal Observatory (MVCO), a site exposed to forcing from the open ocean and located off the southern coast of the island of Martha's Vineyard, in Massachusetts. The MVCO consists of a shore laboratory, a meteorological mast located on the beach, a bottom-mounted "seanode" at a water depth of 12 m, and the Air-Sea Interaction Tower (ASIT), at a water depth of 15 m, which was constructed with CBLAST-low funding during 2002. The intensive observational period for the CBLAST-low program occurred during summer and fall of 2003.

Atmospheric measurements from the ASIT during CBLAST-low were obtained from a vertical array of co-located coherently sampled sonic anemometers, temperature sensors, humidity sensors, and static pressure sensors (Figure 1a). These measurements provide vertical profiles of the momentum, sensible heat, latent heat, kinetic energy, pressure and scalar variance fluxes, as well as dissipation rates for turbulent kinetic energy, temperature variance, and humidity variance estimated from inertial-range spectra. Mean profiles of temperature, humidity and velocity were obtained from a profiling package that moved between 2 and 14 m above mean sea level and additional fixed sensors between 3 and 22 m above MSL. The downwelling radiative heat fluxes were measured by solar and infrared radiometers. The skin temperature and the upwelling IR radiative heat flux were obtained from a pyrometer. The heat fluxes are combined to compute the net heat flux into or out of the ocean.

Oceanic measurements during CBLAST-low were obtained from instruments mounted on and near the ASIT, and from sensors routinely maintained as part of the MVCO. Oceanic turbulence measurements were obtained from near-surface and near-bottom horizontal arrays of co-located coherently sampled acoustic Doppler velocimeters (ADVs) and thermistors (Figure 1b). These measurements provide inertial-range estimates of dissipation rates for turbulent kinetic energy and temperature variance, as well as direct covariance estimates of turbulent momentum and heat fluxes. Measurements of horizontal velocity at the sea surface were obtained with a "fanbeam" acoustic Doppler current profiler (ADCP), which produces spatial maps of the surface velocity along four acoustic beams (Figure 1c). These measurements provide estimates of LC intensity and scale from patterns of divergence and convergence of the surface velocities. Bottom mounted ADCPs near the ASIT, and at the nearby seanode, measured vertical profiles of horizontal velocity through the water column. Near surface profiles of velocity, temperature and salinity were obtained from a high-resolution ADCP and conductivity-temperature-depth (CTD) sensors at the ASIT. Surface displacement was measured at the ASIT using downward looking laser and microwave altimeters. Directional wave spectra are estimated from the ADCP measurements at the seanode.

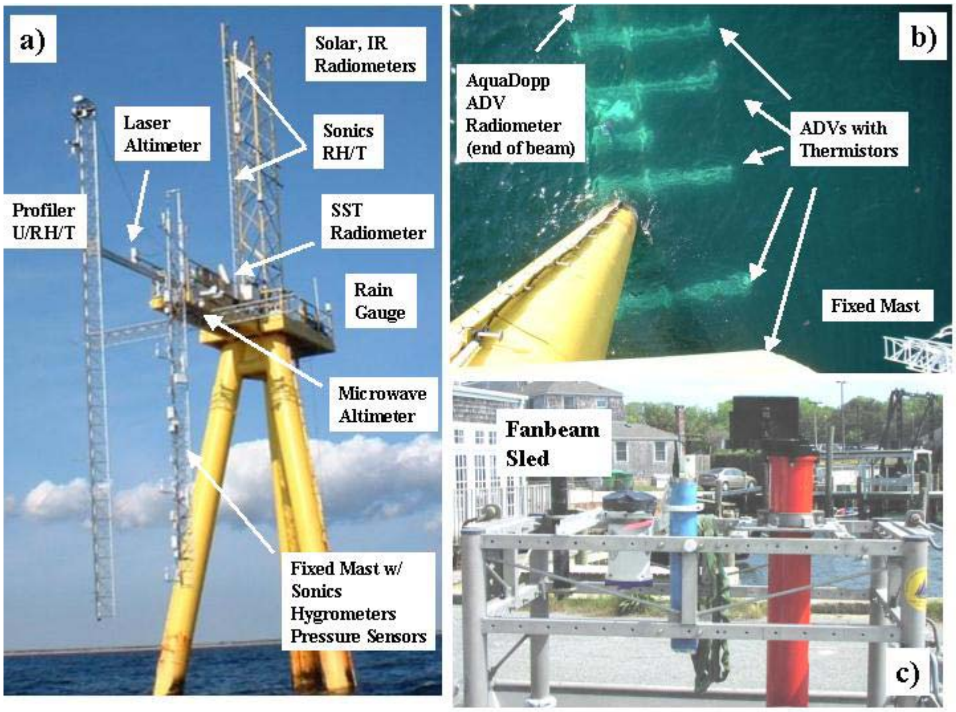

Figure 1. Experiment setup at the ASIT during CBLAST. (a) The air-side instrumentation deployed on the meteorological tower, fixed array, and profiling mast. b) The ocean-side instrumentation deployed on a horizontal beam which was 4 m below the water surface. The acoustic Doppler velocimeters (ADVs) were 2 to 4 m below the ocean surface, depending on the tide. c) The Fanbeam sled that was deployed at 15 m depth on a bottom frame just south of the ASIT.

RESULTS

A primary result is the first (to our knowledge) successful closure of turbulent momentum and heat budgets spanning the air-sea interface (Figure 2). This is an important observational milestone because it means that we can successfully quantify and characterize the flux-carrying processes on the water side of the air-sea interface.

A second result is that the shapes of cospectra characterizing subsurface turbulent transport of momentum and heat are represented accurately by means of a simple model borrowed from the atmospheric literature (Figure 3), in which the controlling parameters are the relevant flux and a scale representing the characteristic size of the flux-carrying eddies.

A third result is that the scaling of LC intensity differs from scalings obtained in open-ocean experiments (Figure 4). The hypothesis is that the relatively young wave age in the coastal CBLAST-low site produces wave-current-turbulence interactions that differ from corresponding open-ocean interactions.

A final result is that the ocean surface layer is better mixed than is predicted by a turbulence model incorporating only effects of shear and buoyancy (Figure 5). An implication is that additional processes, hypothesized at present to be wave breaking and LC, are important in accomplishing turbulent fluxes.

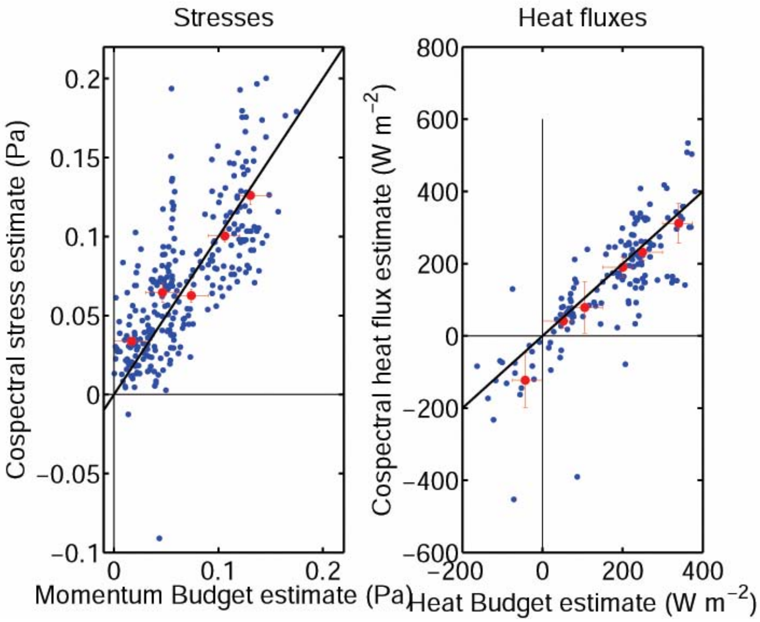

Figure 2. Comparison of atmospheric and oceanic observations showing successful closure of (left panel) momentum and (right panel) heat budgets spanning the air-sea interface. The y axes are the fluxes measured by the water-side turbulence sensors, and the x axes are the fluxes measured by the atmospheric sensors (with minor modifications reflecting other terms in the vertically integrated momentum and heat budgets).

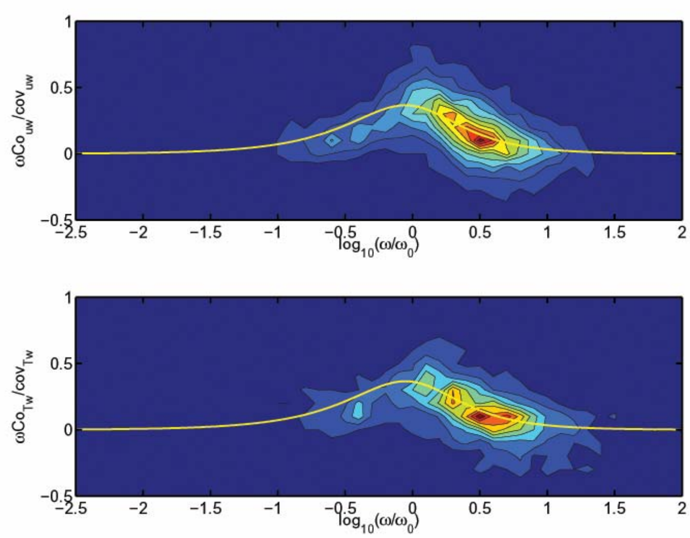

Figure 3. Dimensionless shapes of cospectra corresponding to momentum flux (top panel) and heat flux (bottom panel), indicating excellent consistency with a parametric model borrowed from the atmospheric turbulence literature. The model parameters are the momentum and heat fluxes <u'w'> and <T'w'> and the dominant turbulence scale, represented through the Taylor frozen-turbulence hypothesis by a dominant radian frequency ω_0. Reds and blues correspond to high and low densities, respectively, of measurements. The highest data densities lie along the parametric model curves.

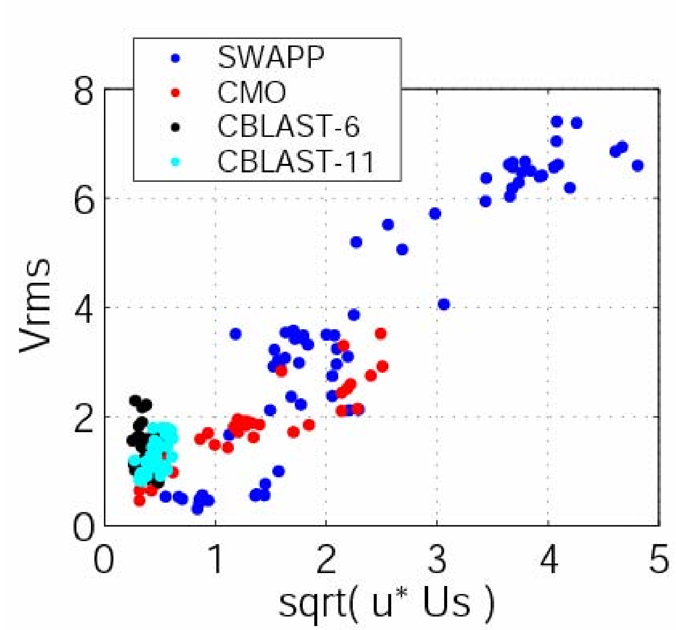

Figure 4. Intensity V_{rms} of Langmuir circulation (LC) as a function of $(U_s u_*)^{1/2}$, where U_s is the surface value of the wave-induced Stokes drift and u_* is the shear velocity. Scaling of LC intensity by $(U_s u_*)^{1/2}$ appears to be appropriate for the open-ocean SWAPP and CMO results, but the coastal CBLAST results indicate a different behavior, suggesting an important role for wave age.

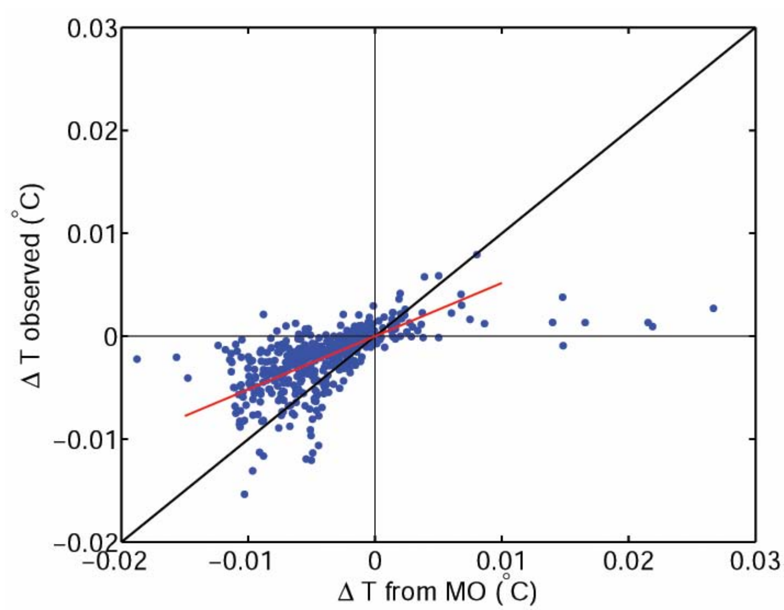

Figure 5. Observed and modeled temperature difference ΔT over a vertical separation of approximately 2 m. The model includes shear and buoyancy generation of turbulence; model inputs are surface stress and buoyancy flux. Observed temperature differences are smaller than predicted by approximately a factor of two under unstable conditions (negative ΔT) and a factor of six under stable conditions (positive ΔT) indicating an important role of processes not included in the model, possibly including wave breaking and Langmuir circulation.